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NUMERICAL STUDY OF SUPERSONIC TURBULENT FLOW OVER SMALL PROTUBERANCES

Semi-Annual Status Report,

January 1, 1976 - June 30, 1976

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by

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This report summarizes the progress made in the study of separated turbulent boundary layers over two-dimensional protuberances. The work covered by this report was performed at the University of Cincinnati between January 1, 1976 and June 30, 1976.

The basic approach centers around the numerical solutions of the turbulent interacting boundary layer equations. The method is essentially an implicit finite difference scheme written for the similarity form of the governing equations and marches from some initial station aft along the surface to the terminal point of interest. It features a time-like relaxation concept which accounts for the boundary value nature of the problem. The calculation commences with certain initial conditions and then through the time dependent approach the steady state solution for a given set of boundary conditions is sought.

After including a number of important modifications into the numerical algorithm it was demonstrated (Refs. 1 and 2) that the method is suitable to handle turbulent separated flows of present interest. Nevertheless, it was reported (Ref. 1) that several refinements remain to be made before the technique can be considered operational. The convergence rate of the

For the second case of the thick separated turbulent boundary layer the initial profile was obtained from a non-interacting calculation to correspond to the boundary layer as it develops along the wall of the UPWT Langley Tunnel. The location of the initial profile is at $s = 72.96$ with the corresponding displacement thickness of 2.8 cm. The interacting relaxation algorithm was subsequently employed between this station and $s = 74.56$ using 81 grid points in the s direction ($\Delta s = 0.02$) with 53 point variable mesh in the normal direction. Figure 2a shows the slow convergence rate for the skin friction at $s = 73.44$ (about 240 iterations are required). When compared to the previous case this represents a fourfold increase in computer time for the same number of mesh points. The skin friction distribution for this case is shown in Figure 2b. It is seen that ahead of the protuberance the skin friction drops and a small separation region develops on the front face of the wave.

The computer time level required for the thick boundary layer calculations was considered unacceptable and an effort has been made to reduce it. The two cases studied differ largely in that for the thick boundary layer the disturbance of the total displacement body from the flat plate value is very small. Therefore, in average the relative change in the total displacement body during two consecutive time iterations is very small. We argued that the numerical truncation error can be of the same order as this relative changes per one iteration, thus leading to very slow convergence rate. We introduced therefore a new variable E in place of the total displacement body δ_T, to be solved for in the second time step. The E is defined by $E = [\delta_T(\zeta,t) - \delta_i(\zeta_i)]/h_s$, where $\delta_i(\zeta)$ is the displacement thickness at the initial station and h_s is a constant of the order of the maximum protuberance height. This new procedure requires only minor changes in the numerical algorithm. Calculations performed with these modifications (with $h_s = 0.01$) and for identical conditions as used for the

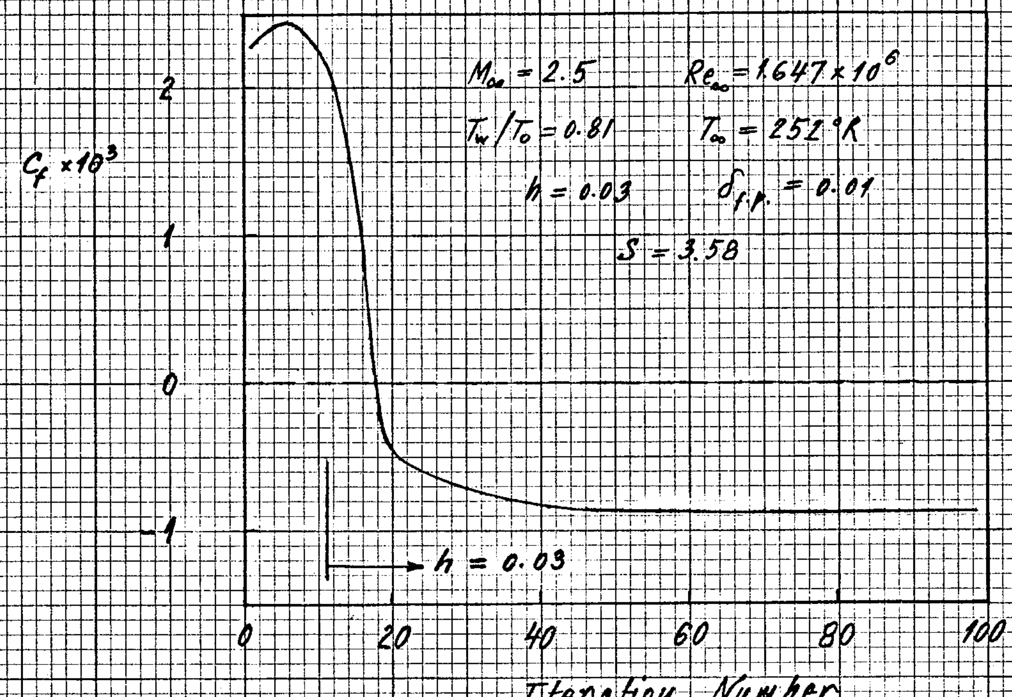

FIGURE 1a CONVERGENCE PROPERTIES OF SKIN FRICTION – THIN BOUNDARY LAYER

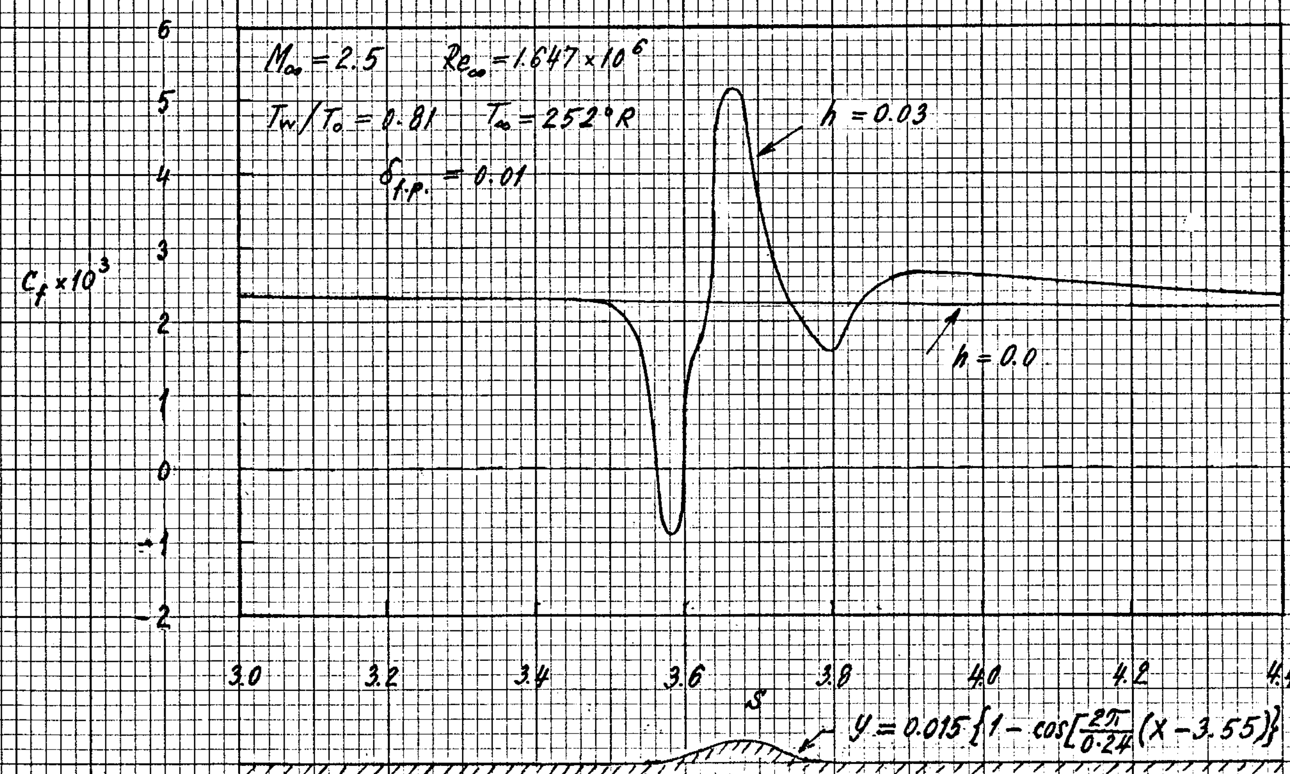

FIGURE 1b SKIN FRICTION DISTRIBUTION – THIN BOUNDARY LAYER

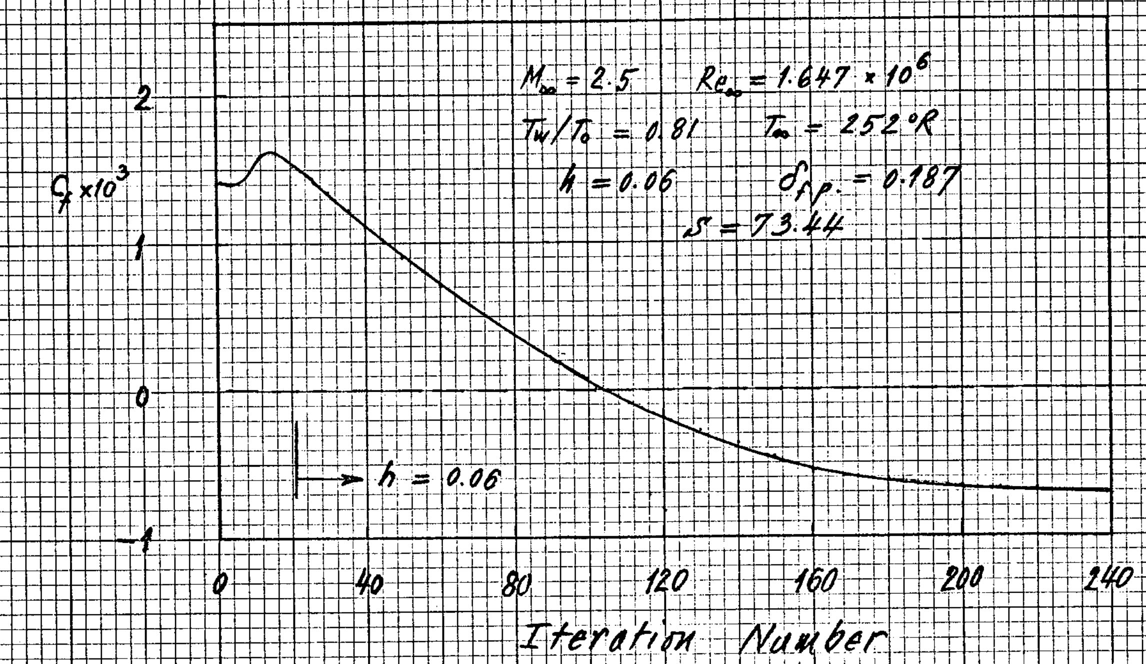

FIGURE 2a CONVERGENCE PROPERTIES OF SKIN FRICTION - THICK BOUNDARY LAYER

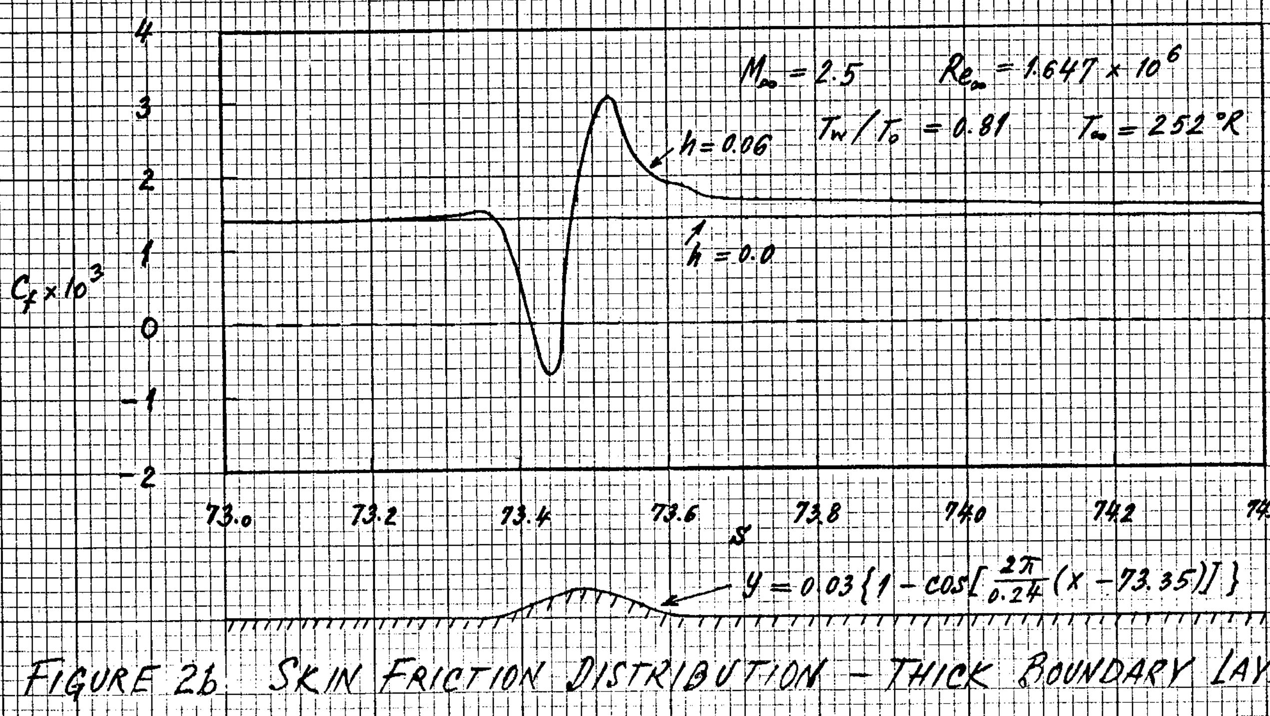

FIGURE 2b SKIN FRICTION DISTRIBUTION - THICK BOUNDARY LAYER

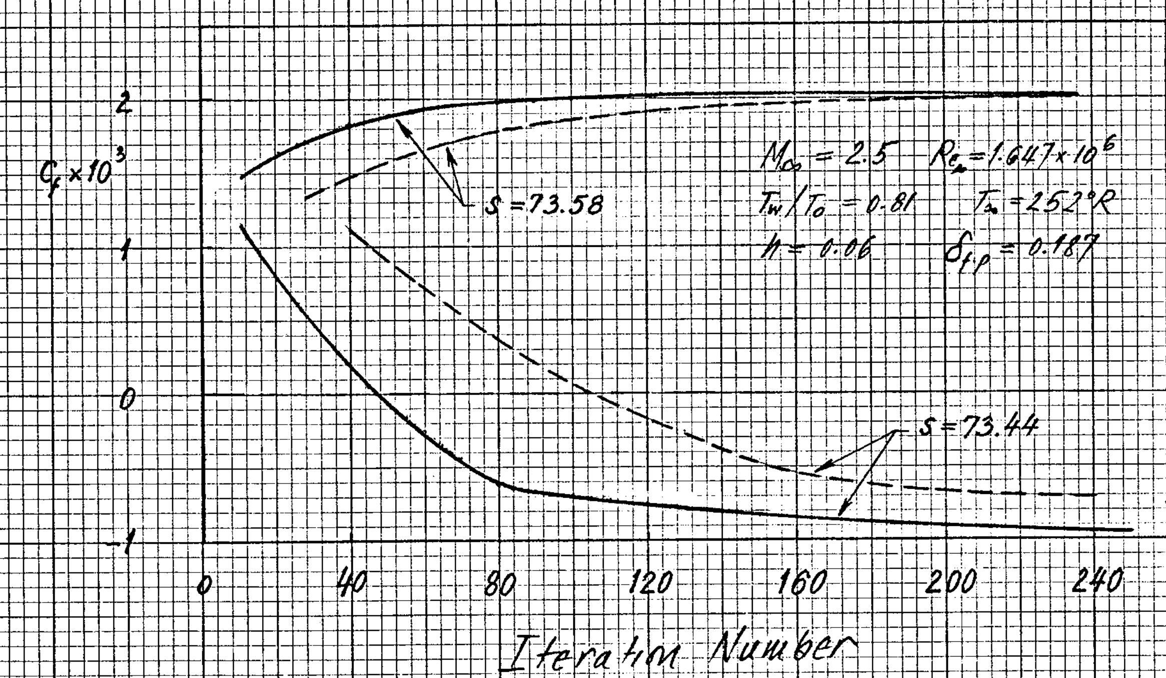

Figure 3 COMPARISON OF CONVERGENCE RATES — THICK TURBULENT BOUNDARY LAYER